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54 **Apparatus for the Wireless Measurement of a Local Physical Quantity**

57 The invention relates to an apparatus for the precise measurement of the distribution of local physical quantities at a site which is inaccessible in normal cases (for example, in living tissue) and for wireless transmission of the values measured and a recognition character for the transponder transmitting the measured values to an evaluation unit located outside of the site of measurement.

By the association of the measured value with the site of the transponder the distribution of the physical quantity to be measured can be determined. Thereby it is, for example, possible to determine the temperature distribution in a piece of tissue, the bending stress at various points of bones, or the body temperature of various experimental animals in a cage. Since the supply of power is done wirelessly through an electromagnetic field, the lifetime of the transponder is not restricted by consumable sources of power.

[text in diagram, clockwise from the top]

HF-Verstärker	=	High-frequency Amplifier
Sendespule	=	Transmitting Coil
Empfangsspule	=	Receiving Coil
NF- Verstärker	=	Low-frequency Amplifier
Anzeige	=	Display
Signalverarbeitung	=	Signal Processing

Apparatus for the Wireless Measurement of a Local Physical Quantity

The invention relates to an apparatus for the precise wireless measurement of the spatial distribution of local physical quantities, preferably of the temperature distribution, at sites which are normally accessible only with difficulty, in particular in living bodies. The apparatus consists on the one hand of a number of miniature transponder devices which are nearly completely monolithically able to be integrated as elements of the measurement apparatus for the registration of the values and sites of measurement of the physical quantities and on the other hand, spatially removed from the site of the measurement and for wireless transmission of the values measured, of a stationary unit for the wireless supply of power and control of the transponder devices and for the evaluation of the information obtained by the transponder device. In this case the transponder is a wirelessly externally powered combined transponder which issues an individually different recognition character as well as simultaneously registering by measurement technology local physical quantities (for example, the local temperature) at a site which is inaccessible in the normal case (for example, in the living body) and transmitting these data wirelessly to an evaluation unit stationed outside of the site of the measurement. By the local physical quantities being able to be associated unambiguously with the site of the respective transponder by the individually different recognition characters, it is possible with the aid of several transponders to register the gradients of these physical quantities (at present the temperature distribution in a piece of tissue). Furthermore, the invention can be used for the purpose of registering various physical quantities (for example, pressure and temperature) simultaneously with the aid of several transponders with accordingly suitable pick-ups for the values measured in a tissue or however even several tissues also spatially separated (for example, several animals in one stall).

The apparatus is suitable for measuring precisely, with the aid of combined transponders, simultaneously on the one hand local physical quantities (for example, the local temperature at various points of a human tumor tissue with the application of hyperthermia procedures to cancer therapy or the pressure ratios at various sites in the jaw bones under stress during chewing or the

pressure ratios in various areas in the beating cardiac muscle) and transmitting the (for example, analog) measured values wirelessly to an evaluation unit and on the other hand processing a (for example, digital) recognition character which is generated by it for the identification of the currently activated transponder. With the use of several combined transponders it is thus possible to measure not only the temperature at a single point but rather the temperature distribution in a cohesive or non-cohesive part of tissue wirelessly. This is particularly important in tumor therapy with the aid of hyperthermia procedures since there the precise registration of the temperature in the core of the tumor and in its edge areas (usually having better circulation and thus cooler) is of striking importance. As long as the physical measured quantity to be detected can be converted into an associated change in electrical resistance or capacitance, it is possible with the use of several transponders to wirelessly monitor on an on-going basis, for example, pulse frequency, EKG, blood pressure, body temperature of one or more humans or animals which are located in the effective range of the control devices.

Externally powered transponders for the wireless measurement of the temperature of objects or organisms have already been known, even in miniaturized form, for some time and have already been tested on individual test animals (DE 32 19 558).

Externally powered transponders for the wireless identification of objects or organisms are already known and have already been in use, also in miniaturized form, for years (Roth, E.: Der Trick mit dem Chip [= The Trick with the Chip]; Stern, Volume No. 42, Oct. 87, Page 251).

The combination of the transmission of an identification signal on the one hand and a measured physical quantity (temperature) on the other hand with the aid of a wireless transponder externally powered by a control device from outside (that is, battery-free) is also known (US 4,075,632).

In order to monitor the temperature distribution of tumor tissue during hyperthermia treatment, it is necessary at present to perform (bleeding) incisions at several points of the tissue and, for example, to introduce light-conducting fibers with sensor bodies into the patient. After the treatment by the therapist the glass fibers must once again be drawn out of the wounds since

they on the one hand are fixed to the control device and on the other hand are very sensitive and break off easily. At the next therapy session the now already healed wounds must be opened anew by incisions and the light-conducting fibers once again introduced into the tumor tissue. This process is repeated with each hyperthermia session and leads to very great stress on the overlying, usually still healthy, tissues.

An apparatus based on the process presented in US 4,075,632 is no better suited for it would mean that per measuring point a 1-centimeter-long dipole antenna must be introduced through the skin outwards and remain there. Thus, for example, in the case of ten points of measurement, twenty fine wires which may not be inflected must remain at the point of measurement, possibly for a lifetime. Apart from the indisputable psychological stress on the patient, this process is unsuitable due to the on-going danger of infection associated therewith (wound channel along the wires). Furthermore, the operating point of the transponder in the process according to US 4,075,632 is insured by a voltage regulator mounted in the transponder, said voltage regulator converting to waste heat the excess energy radiated in. Therewith, however, any miniaturization or even monolithic integration is ruled out since a spatial vicinity of temperature sensors on the one hand and heat-generating stabilizer circuits necessary for the operation of the transponder on the other hand do not permit a precise measurement of the temperature distribution.

The objective of the invention is to specify the local physical quantity with a significantly reduced effect of the transponder on the site of measurement which can be accessed only with difficulty, in particular on the measured value prevailing there.

This objective is realized by a measurement apparatus with the features of the preamble of claim 1, as it is known from US 4,075,632, by the characterizing features of claim 1.

Expedient extensions of the invention follow from the subordinate claims.

The invention opens the possibility of simultaneously measuring several local physical quantities in the interior of living tissue, human or animal, (for example, a tumor) or other

inaccessible sites and associating these measured quantities with the site of the measurement through a recognition character.

For this purpose a generator's frequency of oscillation, which is a function of the physical quantity to be measured each time, is measured where the generator in addition generates an individual recognition character in the form of a digital word. This happens by the generator being coupled to a resonant circuit via a rectifier circuit and drawing power from a high-frequency field whose intensity can be regulated. As soon as the energy drawn from the field is sufficient to operate the generator, it begins to generate cyclically one after the other a continuous oscillation in the timing of a digital word as well as for a certain period of time without timing (for simpler evaluation from the standpoint of measurement technology), each of the physical quantities to be measured being associated unambiguously with the respective frequency of said oscillation. In order to eliminate the dependency of the frequency thus generated on other quantities beyond the physical quantity to be measured—therefore in particular on the unpredictable intensity of the supplied electromagnetic field arising at the site of the combined transponder—the transponder is constructed so that it has an operating point to be recognized wirelessly from outside by the evaluation unit, into which operating point it can be introduced by variation through the control device of the intensity of the supplied high-frequency field and calibrated and operated there. The signal generated by the transponder is detected by the control device or the evaluation unit due to the fact that the transponder draws the energy necessary for the generation of its signals from the field in synch with these signals with the aid of a resonant circuit tuned to the frequency of the supplied high-frequency field. Thereby an amplitude modulation (radio link hop damping) of the supplied field is caused which is registered, demodulated, and processed y the evaluation unit.

The combined transponder is suited not only to the cases of application mentioned above by way of example, but rather (depending on the availability of measured value converters, which convert one physical quantity to be measured into a suitable electrical signal to be processed) for all the other measurement objectives in sites which are only accessible with

difficulty or can move in which a strict distinction and association among a plurality of signals of the same type is necessary and unavoidable.

The advantages achieved with the invention consist in particular of the fact that a local measurement with strict association with the site of the respective measurement of a physical quantity can be performed arbitrarily often over nearly unlimited intervals of time at inaccessible sites without the implanted combined transponder having to be attended to or power supplies (batteries) having to be exchanged. By the exact association of the measured local physical quantities with the use of several transponders designed as the same type in principle but each with a different recognition character and possibly equipped with other measured value converters, either measure entire fields of a physical quantity or fields of different physical quantities can be measured at sites which lie in the effective range of the control devices. In addition it is of importance that the transponders can be designed in microform and can remain at all times in the living body. Thereby the transponder is completely functional for use in case of a possible later measurement becoming necessary even after a rather long time. Through the characteristic of the transponders of having a wirelessly recognizable reproducible operating point, a very precise analog measurement of physical quantities is possible which is not possible with prior-art measurement processes with said auxiliary conditions.

Shown are

Figure 1, a transponder according to an exemplary embodiment of the invention,

Figure 2, a time diagram of the power consumption of the signal generator in the transponder according to Figure 1,

Figure 3, a characteristic line of the frequency of oscillation generated by the signal generator in the transponder according to Figure 1 as a function of the applied operating voltage, said characteristic line being drawn on for the determination of the operating point, and

Figure 4, several transponders according to Figure 1 during their operation by a control and evaluation unit according to the invention.

An exemplary embodiment of the circuit of a combined transponder is shown in Figure 1. An oscillating circuit consists of a coil L and a capacitor C and is tuned to a certain resonant frequency. If the transponder is brought into an electromagnetic AC field with the same frequency as the resonant frequency of the oscillating circuit, then a high-frequency AC voltage arises in this oscillating circuit which is rectified by the diode D and supplies the signal generator G with the voltage required to operate. As soon as the feeding electromagnetic AC field provides sufficient power to operate the transponder, the signal generator G in this transponder generates in cyclical alternation over the period of time $t_{[illegible]}$ in Figure 2 a square or sinusoidal oscillation with constant amplitude and over the period of time $t_{[illegible]}$ in Figure 2 a square or sinusoidal oscillation whose amplitude is in addition still timed in the rhythm of a digital word (for example, 101101111). Thereafter a constant amplitude etc. follows once again over the period of time $t_{[illegible]}$. In Figure 2 a section from this cycle is represented for the purposes of illustration. The frequency of the oscillation in the case of the temperature measurement is determined by a resistor R whose resistance value is a function of the temperature. On the other hand the frequency of the oscillation is undesirably also a function of the operating voltage present at the generator G. In order to eliminate this influence, the generator G is fashioned so that at constant temperature and thus constant resistance value R the generated frequency of oscillation first of all rises with increasing operating voltage and after reaching a maximum drops off once again. The saddle point thus arising in the characteristic line is the operating point of the transponder recognizable from outside by the evaluation unit. This operating point is shifted only as a function of the temperature, that is, therefore of the resistance value R. In Figure 3 the characteristic line of the frequency of oscillation generated by the generator G in the transponder is represented as a function of the operating voltage applied. The combined transponder is calibrated at this operating point so that a reproducible connection between the generated signal frequency in the operating point and the temperature to be measured can be produced. By the operation of the generator G in the transponder, energy is drawn from the feeding high-frequency field, which can be detected by a simple coupling coil. Thereby the radio link hop damping by

the transponder is approximately proportional to the operating current of the signal generator located in the transponder. The operating current in turn is directly linked to the signals generated. Thus the electromagnetic field generated by the control device is therefore damped during the time $t_{[illegible]}$ with the temperature-dependent continuous signal frequency of the generator G in the combined transponder. During the interval of time $t_{[illegible]}$ the damping is done in addition by a superimposed recognition character.

Several combined transponders each with the circuit shown in Figure 1 but recognition characters previously programmed in differently are operated with the aid of the control and evaluation unit shown in Figure 4. A high-frequency generator (VFO) whose frequency is variable generates a high-frequency signal whose power is fed to a transmitting amplifier (PA) via a regulator circuit. This in turn feeds a transmission coil. The high-frequency signal of the transmission coil induces in the oscillating circuit of that transponder whose resonant frequency agrees with the frequency of the VFO a high-frequency voltage. As soon as this voltage is sufficient to operate the transponder selected by the VFO frequency, it damps the field yielded by the transmitting coil in the rhythm of the measurement and identification signals. This radio link hop damping is demodulated with the aid of a receiving coil, a demodulator, and an amplifier and fed to a signal recognition and signal-processing unit (CPU). With the aid of a controller loop the transmitting power is then varied so that the transponder addressed is operated at the operating point (maximal signal frequency). Then the signal frequency of the physical quantity to be measured is associated unambiguously. The value is calculated in the CPU and displayed. Thereafter the identification of the transponder addressed by the special selection of the frequency of the feeding AC field is displayed. Then the CPU varies the frequency of the VFO until the next transponder can be addressed due to the oscillating circuit being tuned to another resonant frequency. Then the same signal processing processes as in the case of the first transponder addressed occur. Thus one after the other all the transponders located in the high-frequency field are addressed and thus the distribution of temperatures registered over a predetermined spatial area.

Claims

1. Apparatus for the wireless measurement of a local physical quantity at a site which is accessible only with difficulty

- with a high-frequency generator in whose radiated high-frequency electromagnetic field a transponder device is disposed at the site which can only be accessed with difficulty, said transponder device in connection with a signal generator generating a low-frequency signal with a frequency dependent on the local physical quantity,
- wherein the transponder device draws its operating power from the electromagnetic field via a receiving element with a rectifier connected thereafter and modulates the electromagnetic field with the low-frequency signal generated by the signal generator,
- and with a receiving device for the modulated electromagnetic field as well as an evaluation device which determines its local environmental quantity from the frequency of the signal generator,
- wherein the transponder device is a miniaturized transponder,
- and as receiving element for the electromagnetic field an oscillating circuit is disposed in the transponder,
- and the signal generator (G, R) has an operating point to be recognized wirelessly by the evaluation circuit,
- and a control circuit connected to the evaluation device (CPU) and to the high-frequency generator (VFO) tunes the frequency of the high-frequency generator (VFO) to the oscillating frequency of the oscillating circuit (LC) of the transponder,

characterized by the fact that

- the control circuit operates the transponder in an operating point with maximal or comparable frequency of the signal generator (G, R) as a function of the operating voltage and that the

evaluation device (CPU) determines the local environmental quantity from a shift of this maximal frequency.

2. Apparatus according to claim 1 characterized by the fact the site which is accessible only with difficulty is living tissue and the miniaturized transponder can be implanted in this tissue.

3. Apparatus according to claim 1 or 2 characterized by the fact the miniaturized transponder generates an additional, programmable recognition character superimposed on the low-frequency signal.

4. Apparatus according to claim 3 characterized by the fact the evaluation unit (CPU) determines the site of the transponder from the superimposed recognition character.

5. Apparatus according to one of the preceding claims characterized by the fact that the superimposed recognition character is digital, that is, a digital modulation of the low-frequency measurement signal.

6. Apparatus according to one of the preceding claims characterized by the fact that several individually programmed transponders are disposed in the high-frequency electromagnetic field at various sites which are normally accessible only with difficulty, each with a receiving element (LC), a signal generator with a temperature-dependent element (R), and a recognition character.

7. Apparatus according to one of the preceding claims characterized by the fact that the local physical quantity is the temperature.

8. Apparatus according to claim 4 characterized by the fact that a spatial distribution of a local physical quantity, in particular a temperature distribution, is determined.

9. Apparatus according to claim 4 characterized by the fact that the transponder registers physical measured quantities of different types, for example, pressure and temperature at the identifiable points of measurement.